

**Petr ŠPAČEK<sup>1</sup>, Pavel ZACHERLE<sup>2</sup>, Zdena SÝKOROVÁ<sup>3</sup>, Jana PAZDÍRKOVÁ<sup>4</sup>,  
Josef HAVÍŘ<sup>5</sup>**

## **MICROSEISMIC ACTIVITY OF THE UPPER MORAVA BASIN AND SURROUNDINGS**

### **Abstract**

This paper deals with description of microseismic activity of the Upper Morava basin and surroundings. The results of the monitoring period 1996-2007 show a regional-scale focusing of microseismic activity within a 40–60 km wide Nysa-Morava Zone of generally NW-SE trend. Sequence of events from 2006 microswarm is analysed in details.

**Key words:** microseismic activity, swarm, Upper Morava basin

### **Introduction**

The increased seismic activity concentrated at the NE part of the Czech Republic is often attributed to tectonic movements within the south-eastern portion of the Sudetic fault system – a pre-Mesozoic structure which has been repeatedly re-activated up to the recent times.

The historical seismicity and recent seismological observations rank this region to one of the two most active regions in the Bohemian Massif with typical macroseismic intensities ranging between  $I_0 \approx 3-5^\circ$  and occasionally reaching  $I_0 \approx 6-7.5^\circ$  MSK (e.g. Kárník et al. 1958; Pagaczewski 1972; Kárník et al. 1984; Procházková 1994).

Two short campaigns of digital local seismic monitoring were carried out in 80s. Since the early 90s the seismic activity of the Eastern and Middle Sudetes has been monitored continuously with permanent and temporary seismic stations in variable arrangements. The following periods of monitoring have confirmed that the seismicity continues up to the present-day (e.g. Kaláb and Holub 1994, Skácelová et al. 1997, Zedník et al. 2001, Havíř J. 2002, Sýkorová et al. 2003, Špaček et al. 2006). At present the monitoring of the eastern part of Sudetes is provided by seismic stations of Institute of Physics of the Earth, Brno (IPE) and Institute of Geonics, Ostrava, while the Trutnov-Hronov area in the Middle Sudetes is monitored by stations of Geophysical Institute, Prague and Institute of Rock Structure and Mechanics, Prague (Fig. 1). This paper deals mainly with microseismic observations in the eastern part of the Sudetic seismoactive zone. Readers interested in the Trutnov-Hronov area are referred to paper Málek et al., 2008.

---

<sup>1</sup> Mgr., Ph.D., Institute of Physics of the Earth, Tvrdého 12, 602 00 Brno, Masaryk university of Brno, spacek@ipe.muni.cz

<sup>2</sup> Ing., RNDr., Institute of Physics of Earth, Tvrdého 12, 602 00 Brno, Masaryk university of Brno, pavel.zacherle@ipe.muni.cz

<sup>3</sup> RNDr., Institute of Physics of Earth, Tvrdého 12, 602 00 Brno, Masaryk university of Brno, zdenka.sykorova@ipe.muni.cz

<sup>4</sup> RNDr., Institute of Physics of Earth, Tvrdého 12, 602 00 Brno, Masaryk university of Brno, jana.pazdirkova@ipe.muni.cz

<sup>5</sup> Mgr., Dr., Institute of Physics of Earth, Tvrdého 12, 602 00 Brno, Masaryk university of Brno, josef.havir@ipe.muni.cz

### **Seismic activity in the Nysa-Morava Zone: 1996-2007**

Seismic stations which have been launched in the Nysa-Morava Zone (NMZ) in the early 90s registered numerous microearthquakes but due to poor coverage of the region by seismic stations it was not possible to estimate the hypocentres within reasonable error limits. Since 1996 first locations of stronger events could have been carried out, the location errors remaining still large. In the period 2001-2003 a small network of 5-7 local seismic stations operated in the central part of the NMZ (see Špaček et al., 2006 for details on individual stations). The results of the 30-month monitoring campaign have shown that the higher number of local stations improved significantly the detection and location limits and reduced the location errors of the events. During the 30 months of data acquisition with 5-7 local stations, the annual number of located microearthquakes increased approximately by a factor of 3 compared with the period January 1996-March 2001. Similarly, the number of registered events increased approximately by a factor of 2. In this respect, the effect of the reduction of the network in 2003/2004 (3 local stations had to be removed due to the termination of a research project) seems to be insignificant. Since 2004, the central part of the NMZ has been monitored by four stations of IPE, and the average annual numbers of registered and located events remained close to those of the 2001-2003 period.

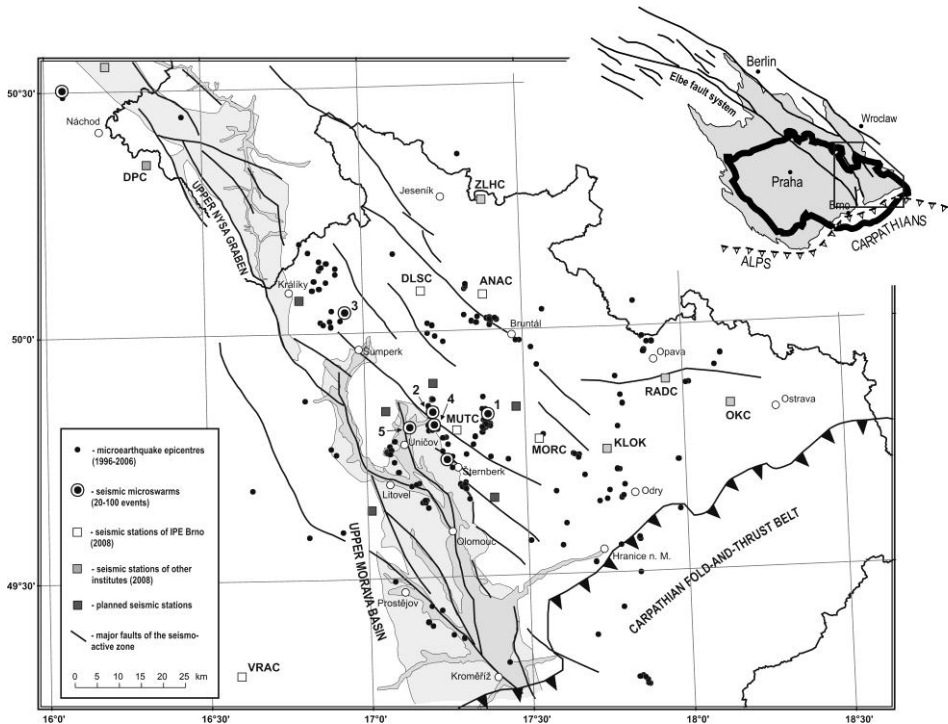
After 12 years of monitoring (1996-2007) the IPE catalogue contains more than 1390 registered and nearly 280 located natural microearthquakes for the region shown in Fig.1. Other more than 200 recorded weak quakes can be associated with conventionally located hypocentres basing on preliminary cross-correlation analysis (see the following chapter).

At a regional scale, the seismic activity is concentrated within the triangular area extending approximately between the towns of Kroměříž, Opava, and Trutnov, called Nysa-Morava Zone (NMZ) by Špaček et al. (2006). Several gaps with diminished or absent seismicity seem to exist within this zone, and two main domains can be distinguished: the relatively smaller Trutnov-Hronov area at the NW and a wider eastern part, which is terminated approximately along a line connecting the towns of Opava, Vrbno pod Pradědem and Staré Město to the north and Kroměříž, Konice and Králíky to the south and west. The eastern boundary is not well constrained due to the lack of local seismic stations.

The VRAC station which is located 40-50km to the SW of the NMZ has low level of seismic noise and records the microseismic events with a very good quality. Since the picking of the seismograms and seismic phase identification are made manually for all IPE stations, we believe that the seismicity to the south of the NMZ is not underestimated.. Similarly, local stations of Institute of Geonics (RADC, ZLHC) have not recorded any seismic events to the north of the NMZ (e.g. Holub et al. 2007 and pers. comm.). We therefore assume our catalogue nearly complete at least for the region shown in the Fig. 1 and  $ML \geq 0.0$  \*).

Significant part of the located events have relatively large location errors (more than 1km in horizontal co-ordinates) because the epicentres lie outside the network of local short-period stations and the distant VRAC, DPC or OKC stations were crucial for location. In spite of the location errors it is clear that most epicentres have tendency to group into several clusters. Within these clusters the seismic activity occurs repeatedly and no significant trend of large-scale migration has been observed over the monitoring period.

Hypocentral depths typically range between 7 and 19 km but are generally not well-constrained, the estimated error exceeding 3km for the events lying outside the network of local stations. The magnitude range of conventionally located microearthquakes is  $ML \approx -0.5$ -2.2 in the eastern part of the NMZ. The Trutnov-Hronov area is characteristic by larger magnitudes, reaching  $ML \approx 3.3$  in the period of the instrumental monitoring (J. Zedník, pers.comm.).



**Fig. 1** Schematic map of the Nysa-Morava fault zone showing epicentres of microearthquakes located in period 1996-2006, currently operating seismic stations and positions of planned seismic stations. Positions of seismic microwarms, main faults with morphological manifestation and pull-apart basin structures are also shown. Numbering of microwarms according to text.

In the period 1996-2007 most of the epicentres seem to concentrate at the northern termination of the Upper Morava basin and its close neighbourhood. Forty five percent of all located events and roughly sixty percent of all registered events fall within the small area of  $35 \times 35$  km in the vicinity of Šternberk and Uničov. The clusters of epicentres tend to align with NNW-SSE to N-S striking tectonic structures, which are partly associated with the Plio-Quaternary sedimentation in the Upper Morava basin.

\*) Magnitude is calculated as an average from all stations used in location. Since large differences often exist between the magnitudes calculated for individual stations,

the absolute value of the magnitude should be taken as a rough estimate only. We are currently testing at IPE new approaches of magnitude calculation.

### **Preliminary analysis of microswarms**

Three types of seismicity can be distinguished with respect to characteristic interevent times and number of events in the NMZ:

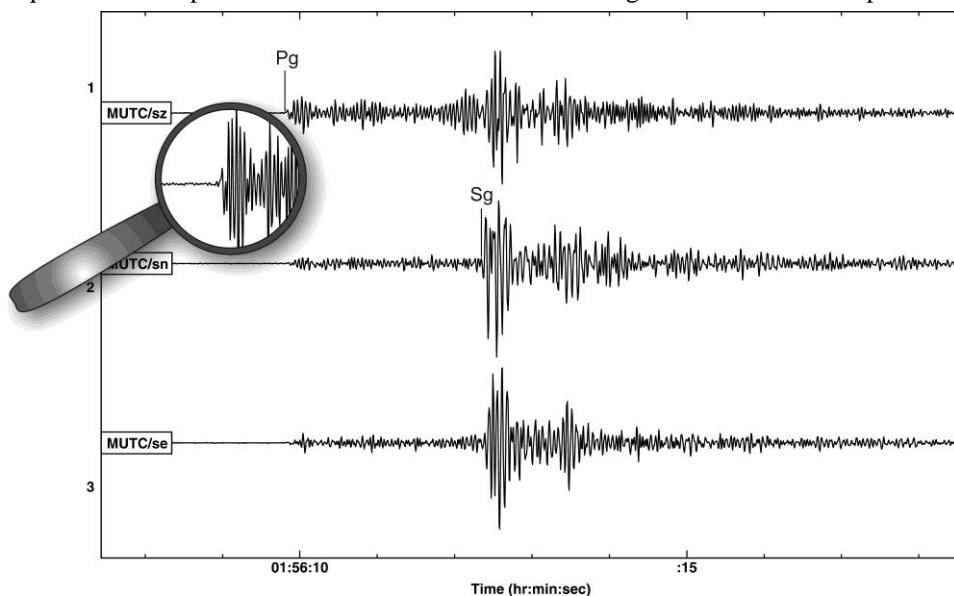
1) Sequences of several events (typically 2 to 5 events above noise level) with interevent times ranging from several minutes to several hours or weeks which are observed in most epicentral zones in the region.

2) Microswarms of larger number of events (up to 100) released during several hours to several days. Such microswarms are less frequent and are characteristic for several sub-clusters with relatively small dimensions located mainly at N to NW margin of the Upper Morava basin.

3) Solitary events without any associated weak microearthquakes.

Sequences of multiple events are characteristic for the NMZ and have been reported since the early periods of monitoring (e.g. Kaláb and Holub 1994, Skácelová et al. 1998, Havř 2002). Both within the microswarms and sequences of earthquakes, multiplets, i.e. events having nearly identical waveforms, are typical, which corroborates their close locations and similar source mechanisms.

To identify the multiplets and their relative amplitudes we use a simple cross-correlation analysis. Due to the low magnitude of the microswarm events we can usually analyse only the seismograms recorded at the nearest station. The strongest event of a sequence is used as a master event. A section of the seismogram is selected which includes all the manually picked events and 12-24 hrs of the record before and after the sequence. This section is analysed in a time-domain to find the local maxima of correlation coefficients. Automatically picked events which correspond to these maxima are manually checked to eliminate problematic events. A master event and a part of a sequence of multiplets of 2006 microswarm is shown in Figs. 2 and 3 as an example.

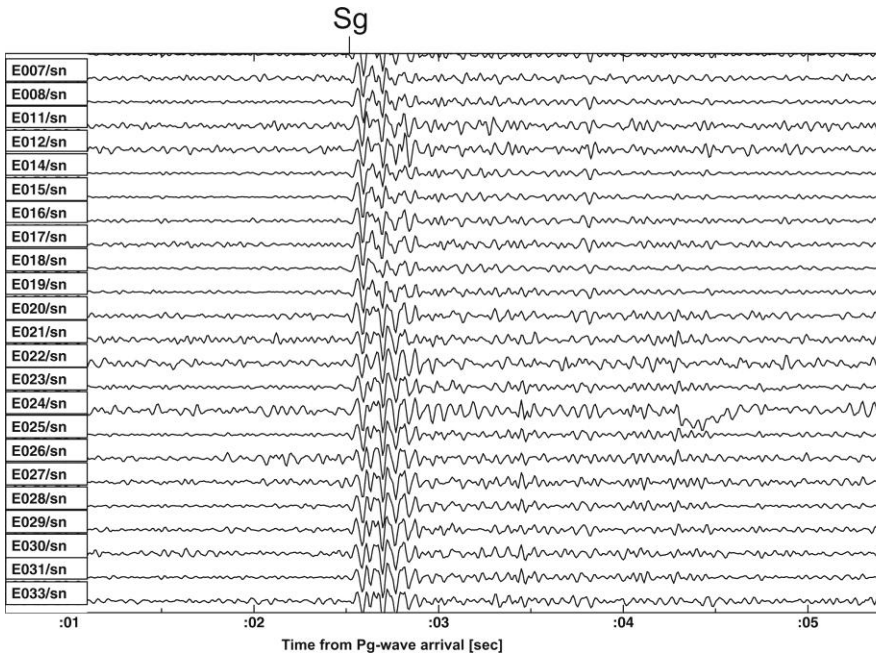


**Fig. 2** Seismogram of the strongest event of the Nov 2006 microswarm (MUTC station),

used as a master event for cross-correlation analysis. Local magnitude at station MUTC is  $M_L=1.3$ . Seismogram is rather complex, with several converted phases and/or reflections (splitting?) both in Pg- and Sg-wave codas.

Five microswarms with larger number of events ( $>30$ ) were analysed using the above described simple technique. Their position of the epicentres is shown in Fig.1 and marked with numbers:

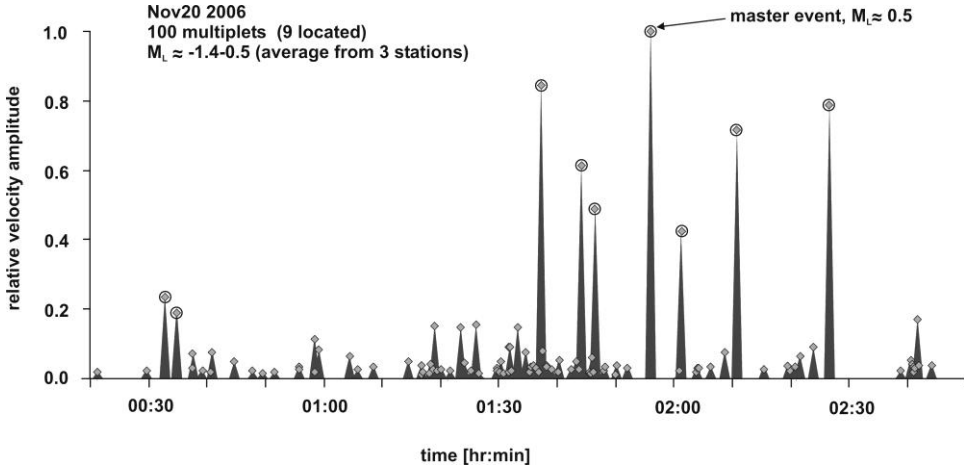
- 1 – 30 multiplets during 2 days, Mar 1998
- 2 – 47 events during 9 days, Oct 2001
- 3 – 33 events during 4 days, Jun 2002
- 4 – 50 multiplets during 5 days, Nov 2005
- 5 – 100 multiplets during 2 hours, Nov 2006



**Fig. 3** Seismograms of a multiplet sequence from 2006 microswarm (MUTC station, Sg-waves at N-channel, separation between E007 and E033 is about 45min). Seismograms of individual events are aligned accordingly to correlation maxima; time in seconds with 00:00 at Pg-wave arrival. Note the high similarity of the events, stable offset of Pg- and Sg-arrival times and variation of possible reflections of unknown origin in the Sg-coda.

Although the seismic sequences and microswarms are highly variable with respect to the interevent times, they have several similar features. The microswarms are usually composed of several higher amplitude events and higher number of low amplitude events, maximum magnitudes reaching  $ML \approx 1.4$ . Within the range of “intermediate” magnitudes (typically,  $-1.0 < ML < 0.0$ ), microswarms obey the Gutenberg-Richter law and b-value of magnitude-frequency distribution is close to  $b=1$  in all five microswarms analysed (examples for the 2006 microswarm are given in Figs. 4 and 5). Above this range the deficit of events disables us to perform well-founded

statistical regressions. Below the  $M_L \approx -1.0$  the deficit is probably due to the incapability to distinguish the signal from the seismic noise.

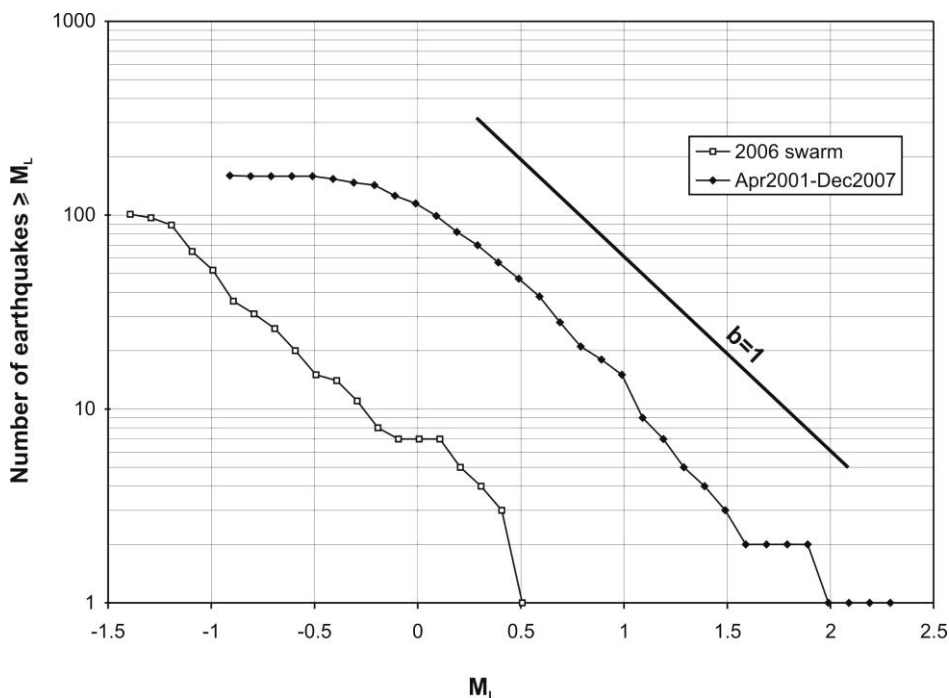


**Fig. 4** Time-amplitude distribution of 100 events of 2006 microswarm. The stronger events come in the second half of the microswarm. Notice two repeating 10-min sequences between 02:00 and 02:30 with similar development.

Unfortunately, it is not possible to make fine correlation-based relocations of the individual foci because only the strongest events are well-recorded at more stations. Most sequences and microswarms express as nearly perfect multiplets, which could be viewed as a possible repeatedly reactivated single focus (within the resolution scale of the seismograms with sampling rate of 100 or 125Hz). However, in several cases (e.g. 2001 swarm) we observed a clear short-term temporal variation of seismic signals both in terms of the shape of the waveform and the difference of P- versus S-wave arrival times. This indicates that both small-scale migration of earthquake foci (minimum 200m within a single swarm) and pronounced changes of focal mechanisms (variable orientations of slip planes or slip directions) occur even in such low-magnitude seismic events.

### Conclusive remarks and future investigation

The results of the monitoring period 1996-2007 show a regional-scale focusing of microseismic activity within a 40–60 km wide Nysa-Morava Zone of generally NW-SE trend. At a local scale the seismic activity concentrates in the N to NW termination of the Upper Morava basin - an active pull-apart structure with Late Miocene-Pliocene-Quaternary sediment accumulation. Roughly sixty percent of all registered events and forty five percent of all located events of the last decade are associated with this structure, and sequences of several multiplets and microswarms are characteristic feature of its seismic activity.



**Fig. 5** Cumulative frequency-magnitude distribution of microearthquakes of 2006 swarm (open squares) and period April 2001-December 2007 (closed diamonds). The latter includes only events with epicentres lying <25km from at least one of the local stations which operated in the whole period (MUTC, MORC, ANAC). The plot shows number of earthquakes with magnitude greater or equal to corresponding value of  $M_L$ .

Magnitude calculated as an average from all stations used in location. Since large differences exist between the values measured at individual stations, the absolute value of the magnitude should be taken as a rough estimate only. Line with  $b=1$  shown for comparison.

Regarding the number of events, their magnitudes and interevent times, the seismic sequences and microswarms of North Moravia are comparable to minor focal zones of the West Bohemia/Vogtland region (the main focal zone of the Nový Kostel is obviously excluded from any comparisons). The spatial co-incidence of Pliocene/Pleistocene volcanic activity and anomalous post-volcanic fluid migration with swarm-like seismicity and increased seismic activity in general, suggests similar causal relations between these phenomena in both regions. However, this co-incidence is observed only at regional scale and it has to be stressed that it is not clear which of these phenomena is a cause and which are consequences. Taking into account the situation in the Upper Morava basin and its close neighbourhood, it can be presumed that pull-apart tectonics or the inversion tectonics of the pull-apart structure might play the crucial role in a process of increased generation of microearthquakes.

The magnitude limits for location of the events lying outside the network of local seismic stations are too high to get an unbiased picture of seismic activity and to carry out correct interpretations of the microswarms.

A thorough manual analysis of the seismograms performed in the last decade shows that we are still only able to locate about twenty percent of the recorded events. Even a simple waveform cross-correlation of selectively handpicked seismograms for 5 microswarms revealed more than 200 foci of weak quakes which can be associated with conventionally located events. The ongoing reconstruction of 3 short-period stations of Institute of Geonics (Fig. 1, e.g. Holub et al. 2007) will significantly improve the location limits in the northern and eastern parts of the NMZ. To get unbiased picture of seismic activity in the most active area, and to understand the phenomena described briefly above, it is crucial to implement several new stations with high sampling rate, which would improve the network geometry in the most active central part of the NMZ. Such an improvement would lower the magnitude limits for location of the events and help to better constrain their source parameters. Then the interpretation of the phenomena described briefly above would be supported by high-quality data and our understanding of pull-apart basin evolution could improve significantly, whether it is in a regime of continuing subsidence or inversion.

## References

- [1] Havíř J. (2002): Recent tectonic activity in the area northwards of Šternberk (Nízký Jeseník Mts.) – Present knowledge. – *Acta Montana IRSM, Ser A*, 20 (124), 97-104.
- [2] Holub K., Rušajová J., and Pazdírková J. (2007): Re-opening of the temporary seismic station at Klokočov (KLOK). *Transactions of the VŠB – Technical University of Ostrava, Civil Engineering Series 7*, 2, 83-90.
- [3] Kaláb Z. and Holub K. (1994): Recent seismic activity in the Opava area (Czech Republic). *Proceedings and Activity Report ESC 1992-1994*, Athens, 153-161.
- [4] Kárník V., Michal E. and Molnár A. (1958): *Erdbebenkatalog der Tschechoslowakei bis zum Jahre 1956*. *Travaux Inst. Géophys. Acad. Tchécosl. Sci.* 69, 411–598.
- [5] Kárník V., Procházková D. and Brouček I. (1984): *Catalogue of Earthquakes for the Territory of Czechoslovakia for the period 1957–1980*. *Travaux Géophysiques* 29, 547, *Academia*, Prague, 155–186.
- [6] Málek J., Brož M., Stejskal V. and Štrunc J. (2008): Local seismicity at the Hronov-Poříčí fault (Eastern Bohemia). *Acta Geodyn. Geomater.* 5, 171-175.
- [7] Pagaczewski K. (1972): *Catalogue of Earthquakes in Poland in 1000–1970 Years*. *Publications of the Institute of Geophysics Polish Academy of Sciences* 51, 3-36.
- [8] Procházková D. (1994): Earthquakes in the Jeseníky Mts. in 1986. *Travaux Géophysiques XXXVI. (1988-1992)*, 28-38. *Geophys. Inst. AS CR*, Prague.
- [9] Skácelová D., Skácelová Z. and Havíř J. (1997): Earthquakes in the northeastern part of the Bohemian Massif recorded by MORC station during the period October 1994 - March 1995. *Bull Czech Geol. Surv.* 72, 1, 49-53.
- [10] Skácelová Z., Skácel J. and Havíř J. (1998): The newest knowledge of seismicity in the region of the Moravia and the Silesia. In: Z. Kaláb (Ed.), *Current Trends in Seismology and Engineering Geophysics*, (1998), 40-48. *Institute of Geonics ASCR, Ostrava*.
- [11] Špaček P., Sýkorová Z., Pazdírková J., Švancara J., Havíř J. (2006): Present-day seismicity of the south-eastern Elbe Fault System (NE Bohemian Massif). – *Stud. geoph. geod.* 50, 2, 233-258.



- [12] Sýkorová Z., Špaček P., Pazdírková J., and Švancara J. (2003): Seismological monitoring of the Dlouhé Stráně pumped-storage power plant. Technical University of Ostrava, Civil Engineering Series 12, 247-251.
- [13] Zedník J., Pospíšil J., Růžek B., Boušková A., Jedlička P., Skácelová Z., Nehybka V., Holub K. and Rušajová J. (2001): Earthquakes in the Czech Republic and surrounding regions in 1995–1999. Stud. Geophys. Geod. 45, 267–282.

